

Very Simple Kaplan Turbine Design

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Nomenclature

b blade height

g gravitational acceleration

H head

k loss coefficient

\dot{m} mass flow rate

P power output

Q volumetric flow rate

r radial direction

R radius

U blade speed

V absolute velocity, subscripts denote stations and components

W relative velocity, subscripts denote stations and components

x axial direction

α absolute flow angle

β relative flow angle

ω rotational speed

θ tangential direction

η efficiency

1, 2, 3, 4 stations through the machine

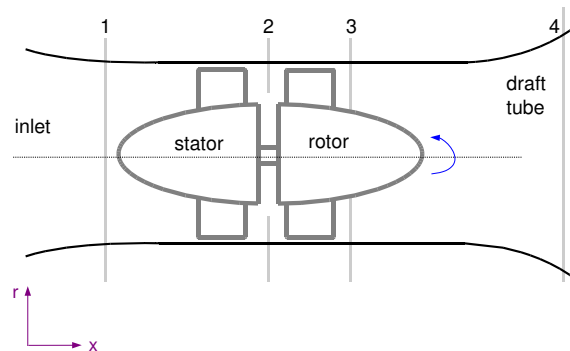


Figure 1: General Arrangement of Kaplan

1 Introduction

This short note indicates how a preliminary design of an axial flow Kaplan turbine can be carried out - see Figure 1 for a cross section of the device. Note that this analysis is approximate and is useful for a first approximation only.

In order to carry out a preliminary blade analysis consider a mean radius through the machine. In order to draw or manufacture the blades you will need to know the inlet and exit angles of the stator (α_1 and α_2) and the rotor (β_1 and β_2). This is shown in Figure 2. In this analysis the effect of blade shape or number is not considered - to a first approximation you can ignore them - simply pick a reasonable shape and a reasonable number of blades.

The approach is to set the flow rate through the machine and then calculate the power output. Once this has been determined the losses and therefore the overall head required to drive the machine are determined - if this exceeds the site head you will need to iterate your design.

Parameters you need to set or guess:

- α_1 Stator inlet angle, set up to line up with incoming flow.
- α_2 Stator exit angle. A value needs to be selected and then checked following the results of this calculation (determines power output)
- β_2 Rotor inlet angle, set to line up with *relative* inlet flow at station 2.
- β_3 Rotor exit angle. A value needs to be selected and then checked following results of this calculation (determines power output)
- Q Flow rate, guess a value and then use this calculation to see if it is reasonable
- R_{2m}, R_{3m} Mean radii at station 2 and 3, pick at start of analysis
- b_2, b_3 Blade heights, pick at start of analysis

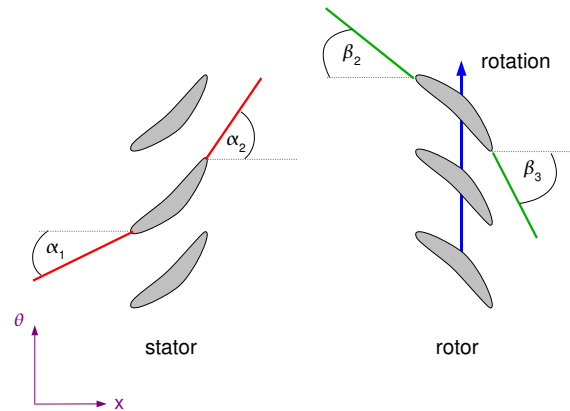


Figure 2: Angles that need to determined for design

- ω Rotation speed of machine

All other quantities are derived from these selections.

2 Power Output

The Euler turbomachinery equation will give us the power output:

$$P = \dot{m}\omega(R_{3m}V_{3\theta} - R_{2m}V_{2\theta}) \quad (1)$$

From velocity triangle at station 2:

$$V_{2\theta} = V_{2x} \tan \alpha_2 \quad (2)$$

where:

$$V_{2x} = \frac{Q}{2\pi R_{2m} b_2} \quad (3)$$

From velocity triangle at station 3:

$$V_{3\theta} = \omega R_{3m} + V_{3x} \tan \beta_3 \quad (4)$$

where:

$$V_{3x} = \frac{Q}{2\pi R_{3m} b_3} \quad (5)$$

Remember that the angles are positive in the direction of rotation! To set β_2 to line up with the exit flow from the stator use the following expression:

$$\beta_2 = \tan^{-1} \left(\frac{V_{2\theta} - \omega R_{2m}}{V_{2x}} \right) \quad (6)$$

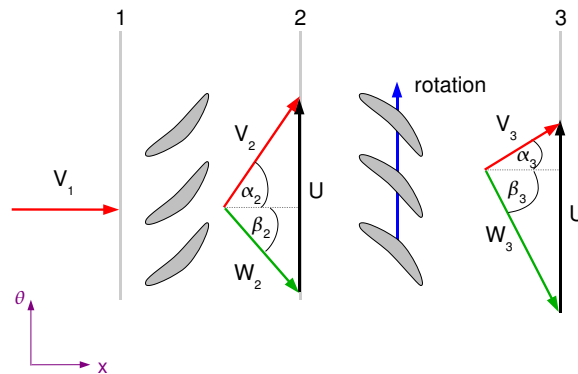


Figure 3: Velocity Triangles for the Axial Flow Kaplan

3 Efficiency and Required Head

Losses are modelled as $\Delta H = k \frac{(\text{velocity})^2}{2g}$ and can be classified into a number of different categories.

- *Pipe Loss* The L2 course will explain how to calculate this, $k = 4f \frac{L}{D}$
- *Guide Vane Loss* $\Delta H_{gv} = k \frac{V_2^2}{2g}$ where $k = 0.05$ typically.
- *Runner Loss* $\Delta H_r = k \frac{W_3^2}{2g}$ where $k = 0.06$ typically.
- *Draft Tube Loss* $\Delta H_{dt} = k \frac{V_3^2 - V_4^2}{2g}$ where $k = 0.15$ typically. To work out V_4 select your draft tube radius and then use continuity. i.e. $\rho A_3 V_{3x} = \rho A_4 V_{4x}$ where $A_3 = 2\pi R_{3m} b_3$ and $A_4 = \pi R_4^2$
- *Bend Losses* $\Delta H_b = k \frac{V_2^2}{2g}$ where $k = 0.05$ typically.

The actual head required is given by:

$$\Delta H_{actual} = \Delta H_{ideal} + \sum \Delta H_{losses} \quad (7)$$

Typically $\Delta H_{losses} = \Delta H_{gv} + \Delta H_r + \Delta H_{dt}$ and:

$$\Delta H_{ideal} = \frac{P}{\dot{m}g} \quad (8)$$

Finally the machine efficiency is given by:

$$\eta = \frac{P}{\dot{m}g\Delta H_{actual}} \quad (9)$$